Atmospheric Propagation Analysis -Gotland, Sweden
Analysis of Atmospheric Transmittance and Aerosol Measurements

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LONG-TERM GOAL

Many new high resolution thermal imaging systems are being produced for the U.S. Navy which will operate primarily in the coastal warfare regions. Submarines and small coastal boat platforms present an optical imaging geometry along a horizontal path only a few meters off the surface of the ocean. It has been found that little or no spectral data exists on the atmospheric transmission which can be expected in the marine atmospheric boundary layer (MABL) for this special imaging geometry. It has been found that the atmospheric propagation models such as LOWTRAN 7 and MODTRAN do not adequately model this region of the atmosphere. As a result of this data and model deficiency, the Atmospheric Propagation Analysis (APA) program was developed at the Space and Naval Warfare Systems Center, San Diego (SPAWARSYSCEN, SD). The APA program conducts spectral measurements of atmospheric transmission in the thermal infrared region across a horizontal path over the ocean surface.

The APA program has made a series of transmission measurements at several different sites which provided a variety of environmental conditions. In order to bound the problem, the first measurements were made in the cold and dry conditions of Adak, Alaska, and the hot and humid conditions of Pensacola, Florida[1]. Measurements under intermediate conditions were made in cool and relatively humid conditions in Vindeby, Denmark[2]. The most recent measurements were made in the Baltic Sea on the small island of Ostergarnsholm located 4 km off the east coast of the island of Gotland, Sweden. These measurements were made in conjunction with the Air Sea Exchange Process Study (ASEPS) program organized by the Risø National Laboratory, Department of Meteorology and Wind Energy, Roskilde, Denmark. This program provided detailed information on the environmental parameters of the site which can be related to the atmospheric transmission measurements and propagation model parameters.

This Atmospheric Propagation Analysis (APA) work sponsored by Dr. Steven Ackleson in Atmospheric and Ocean Optics is a step towards the long term goal of accurate atmospheric transmission prediction in the coastal MABL. The data collected under this program will be used to validate and improve existing atmospheric propagation models.

SCIENTIFIC OBJECTIVES

One of the objectives of the ONR Atmospheric and Ocean Optics Program is to understand the optical properties and processes of the MABL. In support of the MABL work, the current APA Program objective is the quantitative definition of atmospheric degradation encountered in thermal imagery in both the 3-5 μm and 8-14 μm wavebands along typical naval imaging environments and pathlengths.

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APPROACH

The APA measurements were made in conjunction with the Air Sea Exchange Process Study (ASEPS) at the site of a meteorological mast maintained by the University of Uppsala. The purpose of ASEPS is to develop paramaterizations of air-sea exchanges in the MABL by measuring and evaluating the physical properties of the MABL. The Uppsala meteorological mast provides wind speed from four heights, wind direction at two heights, air temperature, water temperature, wave height, and current. Other relevant ASEPS measurements include aerosol size distribution (TNO Physics and Electronics Laboratory, The Hague, The Netherlands) and chemical composition (University of Indiana), and concentrations of atmospheric gases (Risø National Laboratory, Roskilde, Denmark). The ASEPS and APA concurrent measurements provide a unique opportunity to not only measure atmospheric transmission but possibly explain what parameters are effecting the spectral content of the measurements.

The APA technique for measuring atmospheric transmission involves measurement of the signal received over the transmission path from a blackbody source. A CI Systems Model SR-5000 infrared spectrometer is used to measure the signal from the source collimator. This spectroradiometer covers the 1.0 to 14.5 μm wavelength region of the electromagnetic spectrum with the use of a circular variable filter wheel. The average spectral resolution is 0.018 μm in the 3-5 μm region and 0.06 μm in the 8-14 μm region. A complete spectral scan is accomplished in approximately 13 seconds. During each data collection period a series of 5 spectral scans were made approximately every 10 minutes. These 5 scans were then averaged in order to reduce any noise effects.

The collimated source includes a 5-inch diameter, clear-aperture collimator, CI Systems Model SR-9, with a 38-inch focal length optical system. This collimator system incorporates a two-optical element Newtonian telescope system with a 5-inch diameter, off-axis, parabolic mirror and a 1.5-inch focusing secondary mirror. The blackbody source included in the collimator system is a CI Systems, Model SR-2-33. Emissivity of the source is 0.99. Operating temperature is 1000 °C ±1.5 °C.

The 5-inch collimator system is placed at one side of an ocean inlet and the IR Spectroradiometer is placed at the other side of the inlet. All instruments are placed at a height above sea level of approximately 2 meters. Infrared radiance from the blackbody source is recorded across the path during a period of documented atmospheric conditions. Transmittance is calculated as the ratio of the signal response of the long path length over the signal response of a shorter path length. The transmission path length at the Ostergarnsholm site was 908 m. The resulting plots of atmospheric transmission vs. wavelength are then correlated with environmental data provided by ASEPS.

WORK COMPLETED

The Gotland deployment was completely successfully under conditions which ranged from low to high wind speeds, cold to moderate air temperatures, and low to high humidity. Data was collected under the high wind speed, long sea fetch data conditions expected at this site.
Transmission data was collected over an 11 day period beginning 3 May 1997. 7 days of data were collected during the measurement period. Equipment problems and storms prevented data collection on all 11 days.

RESULTS

General trends in all the data sets may be found in Tables 1 through 3. A comparison of transmittance in each of the three prominent transmission bands is compared to LOWTRAN 7 predictions and the trends in relative and absolute humidity, wind speed and direction, and the concentration of large (2.2 to 2 μm diameter) and giant (>2 μm diameter) aerosols.

There are a few preliminary trends worth noting. Transmittance in all bands was highest on 3 May when the lowest relative and absolute humidities were measured, as well as the lowest concentrations of both large and giant aerosols. Although the wind speed of 6-14 m s^{-1} is quite high, the NNW wind direction caused the transmission path to be sheltered from the wind by the bulk of the island of Östergarnsholm. This sheltering effect reduced the amount of white caps and sea spray which would be expected at this range of wind speeds. LOWTRAN 7 predictions are also the highest for this date even though the model cannot take into consideration the sheltering effect of the topography.

All data measured and modeled during periods of long sea fetch (S to SSE) show lower transmittance than the sheltered fetch on 3 May. Transmittance does not seem to correlate with any single meteorological or aerosol parameter. For example, transmittance was lowest in all bands on 8 May. However, the relative and absolute humidities were not the highest encountered, the wind speed was very low, and the concentration of aerosols was relatively low. Under these conditions, a relatively high transmittance would be expected compared to other measurement periods.

The observed discrepancies between the aerosol particle size distributions and the observed transmission may be due to effects that cannot be explained in a simple model based on only meteorological parameters. For example, it was found that when wind speed under long sea fetch conditions and fine aerosol fraction (particle concentrations integrated over sizes smaller than 1 μm) were plotted, two groups appeared with quite different concentrations. In spite of the common meteorological conditions, the air masses are quite different, possibly with different origins. Indeed, the weather maps indicate two different air masses, one originating in clean arctic regions, the other coming from more polluted areas in Europe. This example clearly illustrates that consideration of only the local situation is not sufficient to explain the observed aerosol and transmittance behavior.

Date 1997	RH% avg.	Absolute Humidity gm m-3	Wind Speed m s-1	Wind Direction	**% Trans., 2.8-4.3 μm average**	**PC-TRAN 7** Avg. % Trans., **2.8-4.3 μm**	Large Aerosols 2.2-2 μm diameter dN/dD	Giant Aerosols >2 μm diameter dN/dD
8 May	**65-80**	**5-6**	**2-5**	**SSE**	**50**	**57**	**200**	**0.1**
10 May	85+	6.5	10-15	S	55	53	1000	1
13 May	80	10	2-5	S to SE	55	53	1000	0.1-1.0
11 May	85+	6.3	6-10	S	60	53	900	0.2
12 May	80+	6	2-8	SSE	60	56	1000	0.15
4 May	55-75	4-5	3-7	SSE	65	61	30	<0.1
3 May	**35-40**	**3.5**	**6-14**	**NNW**	**75**	**63**	**30**	**<0.1**

Table 1. Transmittance in 2.8-4.3 μm region sorted in ascending order and compared to LOWTRAN 7 predictions and measured meteorological and aerosol parameters.

Date 1997	RH% avg.	Absolute Humidity gm m-3	Wind Speed m s-1	Wind Direction	**% Trans., 4.3-5.5 µm average**	**PC-TRAN 7** Avg. % Trans., **4.3-5.5 µm**	Large Aerosols 2.2-2 µm diameter dN/dD	Giant Aerosols >2 µm diameter dN/dD
8 May	**65-80**	**5-6**	**2-5**	**SSE**	**35**	**36**	**200**	**0.1**
13 May	80	10	2-5	S to SE	35	32	1000	0.1-1.0
10 May	85+	6.5	10-15	S	40	34	1000	1
11 May	85+	6.3	6-10	S	40	34	900	0.2
12 May	80+	6	2-8	SSE	40	34	1000	0.15
4 May	55-75	4-5	3-7	SSE	45	39	30	<0.1
3 May	**35-40**	**3.5**	**6-14**	**NNW**	**55**	**41**	**30**	**<0.1**

Table 2. Transmittance in 4.3-5.5 µm region sorted in ascending order and compared to LOWTRAN 7 predictions and measured meteorological and aerosol parameters.

Date 1997	RH% avg.	Absolute Humidity gm m-3	Wind Speed m s-1	Wind Direction	**% Trans., 7.3-13.5 µm average**	**PC-TRAN 7** Avg. % Trans., **7.3-13.5 µm**	Large Aerosols 2.2-2 µm diameter dN/dD	Giant Aerosols >2 µm diameter dN/dD
8 May	**65-80**	**5-6**	**2-5**	**SSE**	**60**	**74**	**200**	**0.1**
13 May	80	10	2-5	S to SE	65	69	1000	0.1-1.0
4 May	55-75	4-5	3-7	SSE	75	77	30	<0.1
11 May	85+	6.3	6-10	S	75	72	900	0.2
12 May	80+	6	2-8	SSE	75	72	1000	0.15
10 May	**85+**	**6.5**	**10-15**	**S**	**80**	**71**	**1000**	**1**
3 May	**35-40**	**3.5**	**6-14**	**NNW**	**90**	**79**	**30**	**<0.1**

Table 3. Transmittance in 7.3-13.5 µm region sorted in ascending order and compared to LOWTRAN 7 predictions and measured meteorological and aerosol parameters.

IMPACT/APPLICATION

This is one of the first spectral transmission data sets which has been taken concurrently with measurements of aerosol particle size distribution, aerosol chemical composition, absorbing gasses such as CO2 and ozone, and bulk meteorological parameters. This is also one of the first data sets collected under the high wind conditions frequently found at northern latitudes. This will be an important data set for validating the propagation models under high latitude conditions.

TRANSITIONS

With the publishing of this work in open scientific literature[3,4], we hope to accomplish the bulk of the transition of this data to the scientific community. The data will also be provided to Dr. Kusiel Shifrin, Oregon State University, in support of his work on inverting transmission measurements to derive aerosol particle size distributions.

RELATED PROJECTS

Air Sea Exchange Process Study (ASEPS) - The APA Vindeby data collection effort was done in conjunction with ASEPS. ASEPS measurements included aerosol particle size distribution and composition, trace gas concentrations, and meteorological and oceanographic parameters.

EO Propagation Assessment in Coastal Environments (EOPACE) - Lessons learned in Vindeby were applied to EOPACE surf zone measurements. Further lessons learned at EOPACE will be applied to future APA deployments. Both data sets will be useful for differentiating between surf zone and non-surf zone effects on transmission characteristics.

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